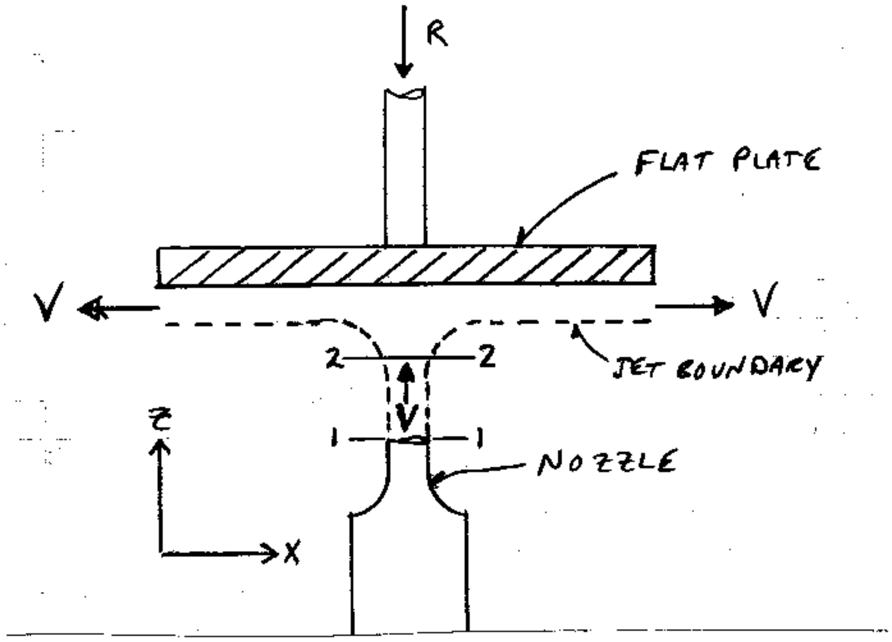
Momentum Study - Force of a Jet on a Surface

Exercise Objectives: Compare the force measured when a water jet strikes a flat plate and a cup to the force calculated by applying the control volume form of the linear momentum equation.

Apparatus: The jet impact apparatus used in this experiment can be fitted with both a flat plate and a hemispherical cup.

Introduction: We know that a jet impacting a shape exerts some force upon the shape.

Theory: Text figures P5.70 and P5.71apply to this laboratory exercise.



To calculate the theoretical force exerted by the jet, we apply a control volume analysis using the laws of Conservation of Mass (see text equation 5.5) and Conservation of Linear Momentum (see text equation 5.17). These laws allow us to determine the force the fluid jet exerts on a surface by evaluating the net rate of linear momentum flow through the control surface.

$$\boxed{\frac{\partial}{\partial t}\int_{cv} \rho \, d\mathcal{V} + \int_{cs} \rho \mathbf{V} \cdot \hat{\mathbf{n}} \, dA = 0} \qquad (5.5)$$

$$\boxed{\frac{\partial}{\partial t}\int_{cv} \mathbf{V}\rho \, d\mathcal{V} + \int_{cs} \mathbf{V}\rho \mathbf{V} \cdot \hat{\mathbf{n}} \, dA = \sum \mathbf{F}_{\text{contents of the control volume}}} \qquad (5.17)$$

The following assumptions apply:

(1) flow is steady.

(2) the body force on the water close to the plate or cup is negligible.

(3) flow is uniform.

(4) speed of jet impinging on flat plate is constant.

(5) flow is incompressible.

Procedure:

a) Theoretical

Define a control volume and coordinate system to analyze the net force of the jet on the flat plate. Use the Conservation of Momentum to solve for the force of the jet.

Perform the same analysis for a turning vane (a hemispherical cup in our case) that rotates the flow through 180 degrees.

b) Experimental

Measure the mass flowrate by collecting a quantity of water in a bucket over a time interval, then weighing the contents. Use the mass flowrate to calculate the jet velocity. Develop a working equation for the jet diameter listed on the apparatus so that you can calculate jet velocity in feet per second from this measured quantity.

Adjust the spring tension of the apparatus so that the balance beam just lifts off the support. At this point, the weight of the balance beam and fixture is exactly balanced by the spring force.

Your objective is to measure the force due to the jet for varying flowrates. You may either fix the reaction force by placing a weight at a certain distance and adjust the flow rate to reach equilibrium; or, fix the flow rate and adjust the moment arm of the weight balance. Equilibrium is attained when the balance beam is just off the support. Measure the flowrate, then use the equation you developed above to determine the jet velocity.

Take a sufficient number of data points covering the full range of flowrates.

After taking data for the flat plate, move to the apparatus with the hemispherical cup and repeat the procedure.

When you have completed taking data, you should have experimental values for the force of the jet, $\mathbf{F}_j$, and velocity of the jet, $\mathbf{V}_j$, for a range of velocities for both turning vanes. Plot these results. Since you know from your analysis that the jet force is a function of the square of the velocity, you may linearize your experimental data by plotting $\mathbf{F}_j$ versus $(\mathbf{V}_j)^2$. Use a linear curve fit to fit lines to your experimental data.

Compare the slopes of the lines from the plots of experimental results with those that theory predicted. Were the results for the flat plate better, same, or worse than those obtained using the hemispherical shell? What are some possible causes for those differences? Find an effective turning angle, β, that will correct for the losses you discovered for the hemispherical shell.

Reporting Requirements: Memorandum format by group. Include the system sketches, derivations, smooth copy of data and reduction, and plots as enclosures.

Supplementary Reading: A Brief Intro to Fluid Mechanics, Young, Munson, Okisishi (1997) Section 5.1, 5.2.1, 5.2.2

Related Text Problems: 5.70, 5.71